Estimation Of Long-Term Sediment Loads In The Fitzroy Catchment, Queensland, Australia

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EXTENDED ABSTRACT

With a catchment area of nearly 140,000 km^2, the Fitzroy discharges a significant amount of sediment to the Great Barrier Reef lagoon. Sediment discharge is related to water turbidity which has a direct impact on coastal ecosystems. Previous estimates of the long-term average sediment load of the Fitzroy vary greatly 1.3 - 2.5 Mt (1 Mt = 10^9 kg). These estimates, however, were mostly based on an extrapolation of sediment loads from other catchments in Queensland. In addition, sediment loads from major tributaries of the Fitzroy have not been assessed for internal consistency in the estimated sediment loads.

Measured total suspended solids (TSS) concentrations from six sites in the Fitzroy were used to develop sediment rating curves. Sediment rating curves were corrected using smearing estimates to remove an inherent bias as a result of log-transformation. These rating curves combined with streamflow data were used to estimate long-term mean annual sediment load of the Fitzroy and its main tributaries for a common 30-year period 1974-2003.

Sediment rating curves for the six sites show considerable similarity, and variation in sediment discharge at given flow rates is considerably larger than between-site variations in the expected sediment discharge at the flow rate. The mean annual sediment load was estimated to be 3.09 Mt for the Fitzroy at the Gap for the 30-year period (see Table below). Most of the sediment of the Fitzroy comes from the Nogoa and Comet subcatchments. The combined loads of the four major tributaries are consistent with the total load estimated for the Fitzroy at the Gap. Load estimated for the MacKenzie site appeared to be low. At given level of runoff, sediment concentration on average was highest for the Nogoa and Comet subcatchments, and the lowest for the Isaac.

An intensified period of water quality monitoring since 1993 coincided with a period of relatively low streamflow. Flow for the period 1994-2003 was about half, on average, of the 30-year period investigated.

Site location, mean annual flow, and sediment loads in the Fitzroy for the period of 1974 – 2003.

Gauging Station	River	Location	Catchment area (km^2)	Mean annual discharge (GL)	Mean annual sediment load (Mt)	Upper 95% prediction interval of load (Mt)	Lower 95% prediction interval of load (Mt)
130219A	Nogoa	Duck Ponds	27,130	614	1.23	2.06	0.13
130504A	Comet	17.2 km	16,422	402	0.576	1.02	0.083
130401A	Isaac	Yatton	19,719	2,569	0.391	0.47	0.030
130105A	MacKenzie	Coolmaringa	76,645	3,922	1.73	3.04	0.26
130322A	Dawson	Beckers	40,500	853	0.246	0.44	0.064
130005A	Fitzroy	The Gap	135,757	5,227	3.09	5.19	0.63

1. INTRODUCTION

The Fitzroy is the largest coastal catchment in Queensland. With a catchment area of nearly 140,000 km^2, the Fitzroy discharges a significant amount of sediment to the Great Barrier Reef lagoon. Sediment discharge is related to water turbidity, which has a direct impact on coastal ecosystems. It is therefore important to accurately determine the amount of sediment the Fitzroy carries to the coastal areas. The Fitzroy basin is a priority catchment in the National Action Plan for Salinity and Water Quality (NAPSWQ), and has been identified as a high impact catchment in the Great Barrier Reef Marine Protection Plan.

Previous estimates of the long-term average sediment load of the Fitzroy vary greatly. Belperio (1979) estimated a mean annual load of 2.5 Mt (1 Mt = 10^9 kg) for the Fiztroy by assuming the sediment rating curve (an empirical relationship between water discharge and sediment discharge) derived for the Burdekin river.. Moss *et al* (1992) assumed a constant flow-weighted sediment concentration of 250 mgL^{-1} for catchments south of the Burdekin. This would lead to a mean annual load of 1.3 Mt using the streamflow data for the Fitzroy at the Gap (see Table 2). Neil and Yu (1996) modelled sediment rating curves for six catchments in Queensland, and developed relationships between runoff (mm) and mean sediment load per unit area per unit runoff (t $km^{-1}mm^{-1}$). Using this method, Neil and Yu (1996) estimated a mean annual sediment load of 2.4 Mt for the Fitzroy under natural conditions and up to 10.3 Mt when the catchment is fully disturbed as a result of agricultural production and urbanisation.

Previous investigations are mostly based on extrapolation of results from other catchments in Queensland. Estimates of sediment loads of the Fitzroy have been derived from measured total suspended solids (TSS) concentrations for the catchment. In addition, sediment loads from major tributaries of the Fitzroy have not been assessed for internal consistency in the estimated sediment loads. Spatial distribution of sediment load and sediment budget on a long-term basis are important for validating spatial sediment yield models such as SedNet (Fentie *et al*. 2005).

Ideally, streamflow and TSS concentration are continuously monitored so that the total sediment loads can be determined by integrating instantaneous loads for the required period at a particular site. In the absence of extensive and continuous long-term monitoring of TSS concentrations, sediment load is commonly estimated using sediment rating curves. With sediment rating curves, long-term flow records can be used to estimate instantaneous loads so that the total or average loads can be estimated for the required period. The limitations of using rating curves are many and generally known. These include a lack of sediment samples during high flows, sampling for certain flow ranges, disparate sediment discharge during rising and falling stages of the hydrograph, variations in TSS concentration as a result of different sediment generation mechanisms and different locations of the centre of storm events. Large variations around the rating curves lead to uncertainties about the functional form of the rating curves and parameter values associated with the rating curves. Despite these limitations, with irregularly collected TSS concentration data, this method remains the best available, and most accepted one to use to estimate long-term sediment loads.

The objectives of this paper are to develop discharge-sediment load relationships for six sites in the Fitzroy catchment, to estimate long-term sediment loads for a common 30-year period, and to assess the quality of the estimated sediment loads.

2. DATA AND METHOD

The main tributaries in the Fitzroy catchment are the Nogoa, Comet, Isaac, and Dawson rivers. The MacKenzie collects flows from the Nogoa, Comet, and Isaac. It then joins with the Dawson from the south to become the Fitzroy (Fig. 1). The long-term mean annual streamflow of the Fitzroy is 5227 GL at the Gap (Table 2) or 39 mm. The Isaac generates most water per catchment area with 127mm yr^{-1}, while the Dawson has the lowest runoff of 21 mm yr^{-1} among the four major tributaries.

The Queensland Department of Natural Resources and Mines collects water quality data, including TSS concentration, under its Surface Water Ambient Network program, since the 1970s and more intensively since 1990s. This program provides a large amount of TSS concentration data to allow an estimation of long-term sediment loads throughout the Fitzroy catchment. For this study, all available TSS concentration and flow data were extracted from the Department's HYDSYS surface water database for the period between 1974 and 2003 when the data were most complete.

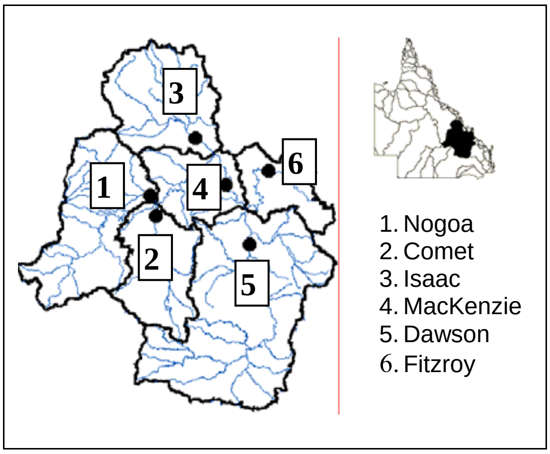

Figure 1. Subcatchments and TSS sampling sites in the Fitzroy catchment.

Long term flow data were available from 1974 at all sites except the Nogoa where flow monitoring commenced only in 1993. The streamflow at this site prior to 1993 was estimated by taking the differences between flows of the Comet River at 17.2 km (130504A) and that of the MacKenzie River at Carnangarra (area = 45,370 km^2) which is just downstream the Nogoa-Comet junction. The estimated and measured flows were compared for the period when streamflow was measured at all three sites (Fig. 2). The scatter for high flows is small, although at low flows there is a large amount of scatter around the 1:1 line. When the sediment load was estimated using observed and the estimated flow for the Nogoa, the difference is no more than 6% in estimated sediment loads for the period 1993 and 2003. Streamflow data for the Nogoa were extended to 1974 to create a complete data set for the 30-year period from October 1973 to September 2003 for all six sites in the catchment.

Total suspended sediment concentrations were measured occasionally from the 1970s at all sites except for the Nogoa where intensive sampling began in 1993 under the Department's Surface Water Ambient Network program. Both low (<80 percentile) and high flows (>80 percentile) were well sampled at all sites, however the upper 2 percentile of flows were well sampled only at the Nogoa and Fitzroy sites, moderately sampled in the MacKenzie and poorly sampled in the Comet, Isaac, and Dawson sites. In terms of maximum discharge sampled relative to the maximum discharge on record, the ratio was 65% for the Fitzroy site, 45% for the Comet and Dawson sites, 35% for the Nogoa, 18% for the MacKenzie, and was only 5% for the Isaac.

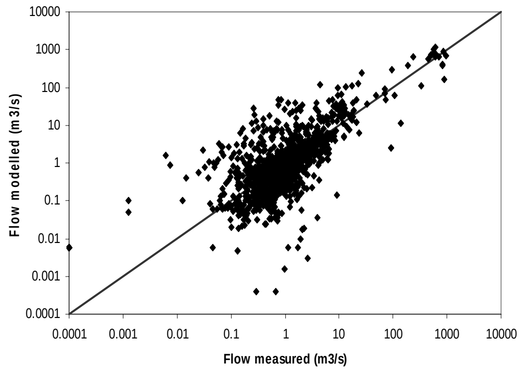

Figure 2 Modelled versus measured flow, Nogoa River at Duck Ponds for the period between 1993 and 2003.

Table 1. Comparison of measured and estimated mean annual flow and sediment loads for the Nogoa site (1993-2003).

	Mea'd	Est'd	Estimation Error (%)
Flow (GL)	2,513	2,668	6.1
Load (Mt)	3.54	3.75	5.9

Table 2. Site location, mean annual flow, and sediment loads for the period of 1974 – 2003.

Gauging Station	River	Location	Catchment area (km^2)	Mean annual discharge (GL)	Mean annual sediment load (Mt)	Upper 95% prediction interval of load (Mt)	Lower 95% prediction interval of load (Mt)
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Data on TSS concentrations were collected at irregular time intervals, often three to four times a year. All the TSS data were used to develop rating curves for the site. Measured instantaneous sediment discharge was calculated using TSS concentrations and corresponding flow measurements in the form of:

$$Q_s = x * Q * C \qquad (1)$$

where Q_s is the instantaneous suspended sediment loads (t/d), Q the flow rate (m^3/s), C is the TSS concentration (mg/L), and x is a unit conversion factor (0.0864).

Measured instantaneous suspended sediment discharge was plotted against the flow rate for each site and rating curves were developed in the form of:

$$Q_s = a\, Q^b\, C_f \qquad (2)$$

where a and b are regression constants using log-transformed flow and sediment data, and C_f is a correction factor to remove an inherent bias introduced as a result of log-transformation (Ferguson 1986). Smearing estimate was used to calculate this correction factor (Duan 1983):

$$C_f = \sum_{i=1}^{n} \frac{1}{n}\, 10^{\varepsilon_i} \qquad (3)$$

where ε_i is the error term, or the residual, for each measurement:

$$\varepsilon_i = \log Q_{s_i} - \left(a + b \log Q_i\right) \qquad (4)$$

and n the sample size. Standard error of load estimates, *SE,* was calculated as:

$$SE = t\, s \left(1 + \frac{1}{n} + \frac{(\log Q_i - \overline{\log Q})^2}{S_{QQ}}\right)^{0.5} \qquad (5$$

where t is the Student's t distribution, $s = \sqrt{s^2}$ where s^2 is the variance, n is the sample size, and S_{QQ} $= \sum_{i=1}^{n} \left(\log Q_i - \overline{\log Q}\right)^2$.

These sediment rating curves were then used to convert continuous discharge measurements into instantaneous sediment discharge estimates. More detailed flow data were used in this study, while previous estimates of sediment loads were based on monthly and daily flows (Belperio 1983; Neil and Yu 1996). The time interval over which the flow rate is assumed to be constant varies as significant change in water stage occurs. For the Fitzroy at the Gap, for instance, about 50% of flow was recorded at time intervals less than six hours, and 85% of the flow recorded at time intervals < 12 hours. Estimated sediment discharge was integrated to determine long-term sediment load for the 30 year period between 1974 and 2003.

3. RESULTS AND DISCUSSION

Rating curves developed for the six sites are presented in Fig. 3. The grey plots under each graph show all data from all sites to indicate the distribution of TSS concentrations relative to other sites in the Fitzroy catchment. Sample size, estimated parameter values for rating curves are presented in Table 3. Table 3 also includes a sediment rating curve developed using all available TSS concentration data from all six sites.

Table 3 Sample size (n), estimated model parameters for ratings (a and b), and standard errors (ε), for the six sites in the Fitzroy catchments where sediment dicharge (Q_s) is in td^{-1} and discharge (Q) is in m^{3}s^{-1}.

Rivers	n	a	b	ε	r^2
Nogoa	95	6.62	1.53	2.36	0.89
Comet	53	22.9	1.30	1.98	0.94
Isaac	101	5.68	1.11	3.29	0.92
MacKenzie	99	4.44	1.28	1.96	0.92
Dawson	66	8.45	1.18	1.47	0.94
Fitzroy	116	2.45	1.39	1.71	0.95
Combined data set	530	3.28	1.27	2.64	0.92

Fig. 3 shows that of the four major tributaries of the Fitzroy, the Nogoa and Comet have higher sediment discharge at a given flow rate, especially during high flows. During low flows, the sediment discharge is generally lower for the Nogoa than that for the Comet. The Isaac has the lowest TSS and sediment discharge values of all sites, although TSS measurements at high flows are very limited at the site. The MacKenzie receives water and sediment from the Nogoa, Comet, and Isaac subcatchments and the TSS concentrations here appear to be diluted by streamflow from the Isaac subcatchment. In the Dawson River, the TSS concentrations lie in the mid-ranges although measurements of TSS

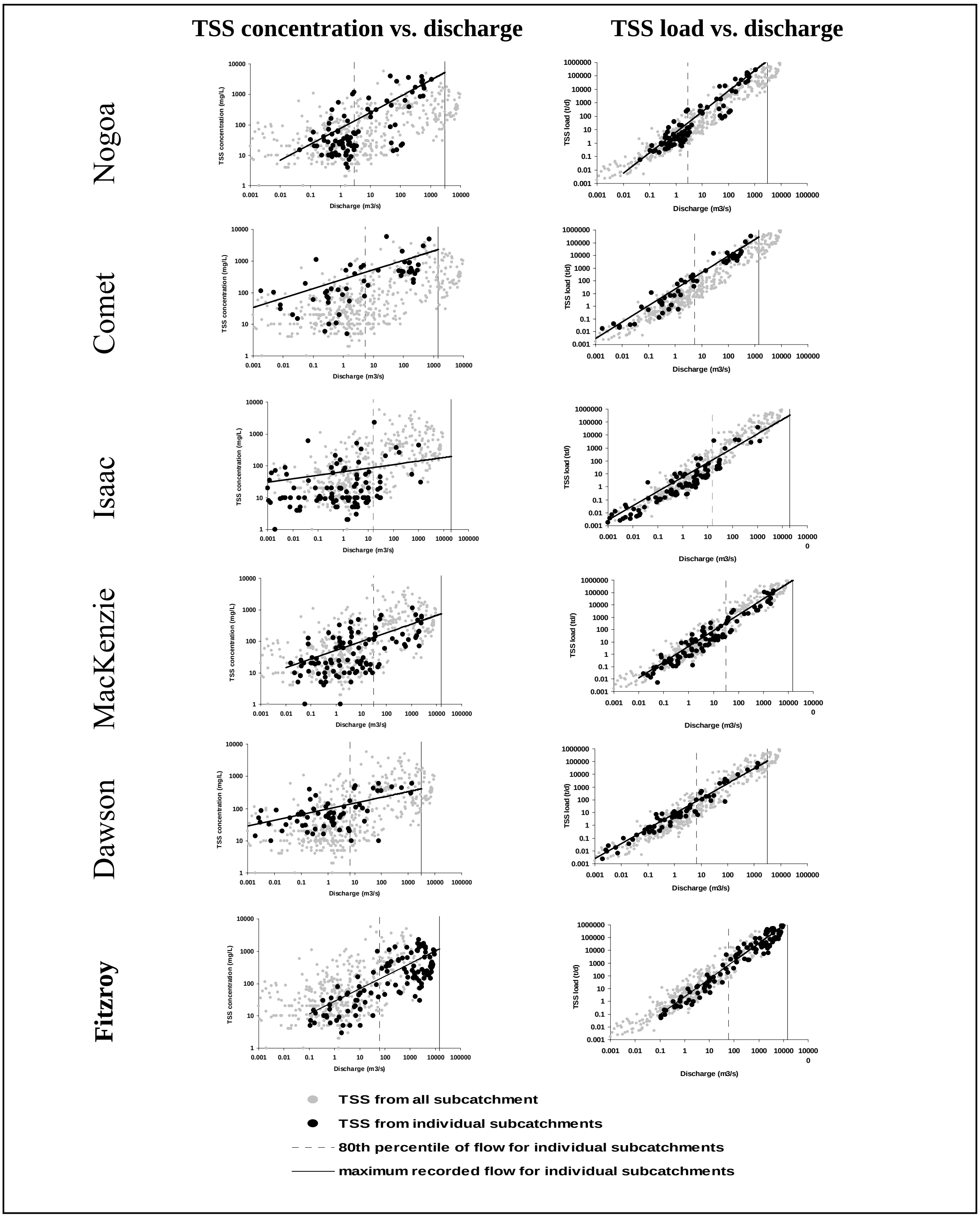

Figure 3. Sediment – flow relationships in the Fitzroy catchment

concentration at high flows are not well represented. The Fitzroy site receives water from MacKenzie and the Dawson. . Fig. 3 shows that the Fitzroy and MacKenzie sites have similar sediment rating curves, and TSS concentrations remain relatively low at the two sites.

It is interesting to note that the variability in the sediment-discharge relationship at any one site is greater than the variation among difference sites. Variations in the expected sediment discharge among the six sites are considerably smaller than the variations in measured TSS concentrations at a given site. From Table 3, it can be seen the standard error for the rating curve using combined dataset is of a similar magnitude when compared to the standard error for individual sites.

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Using all the available concentration data, the flow-weighted TSS concentration of the Fitzroy at the Gap is 533 mgL^{-1}. The average TSS concentration based on the long-term sediment load and streamflow from Table 2 is 591 mgL^{-1}. In both cases, the average TSS concentration was significantly higher than 250 mgL^{-1}, a value assumed by Moss *et al* (1992) to assess sediment exports from Queensland catchments.

Of the four major tributaries of the Fitzroy, the Nogoa has the highest sediment load, followed by the Comet, the Isaac and then the Dawson subcatchments. The same pattern holds in terms of sediment yield (sediment load per unit area). The combined catchment area of the four major tributaries is 103,771 km^2, or 76% of the catchment area of the Fitzroy. The combined load from the four tributaries is 2.44 Mt yr^{-1}. If the load is adjusted by taking into account the difference in the catchment area, the projected load of the Fitzroy at the Gap, based on estimated loads of the four tributaries would be 3.19 Mt yr^{-1}, which is quite consistent with estimated load at the site of 3.09 Mt yr^{-1}. Estimated sediment load of the MacKenzie was 1.73 Mt yr^{-1} (Table 2), some 0.47 Mt less than the combined load from the Nogoa, Comet and Isaac. This would suggest a net loss or deposition of sediments along the reaches downstream from the three sites on the tributaries and along the MacKenzie upstream Coolmaringa. On the other hand, the combined load from the Mackenzie and the Dawson is 1.98 Mt yr^{-1}, which is considerably less than the estimated load of 3.1 Mt yr^{-1} for the Fitzroy at the Gap. The sediment budgets for the Dawson, MacKenzie, and Fitzroy indicate a considerable addition of sediments along the reaches between the three sites. It is highly probable that the sediment load of the MacKenzie at Coolmaringa was underestimated, because it is unlikely to have dramatic fluctuations in deposition and erosion along the lower catchment reaches .

Confidence intervals for load estimates at 95% level are presented in Table 2. Prediction uncertainties were determined for individual time intervals using equation (5) and then integrated over the 30 year period. The average 'error bar' (half the confidence interval) is 74% on average, ranging from 56% for the Isaac to 81% for the Comet.

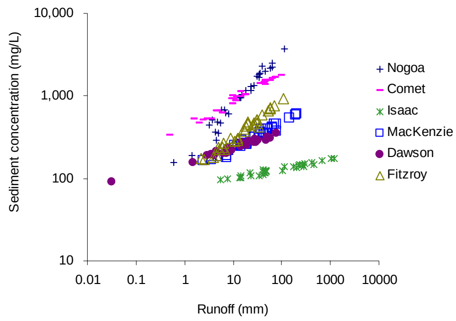

Figure 4. Mean annual runoff versus flow-weighted sediment concentration in the Fitzroy catchment.

The relationship between runoff and flow weighted mean annual sediment concentrations shows three distinct clusters for the Fitzroy catchment. The Nogoa and Comet have the highest sediment concentration for a given level of runoff in the Fitzroy catchment. However, in dry years with low runoff, the sediment concentration of the Nogoa is considerably lower than that of the Comet, while during wet years, Nogoa generates higher sediment loads. The second group consists of the MacKenzie, Dawson and Fitzroy. In this group there is little difference between the sites during drier years. For wetter years, however, the Fitzroy has a higher sediment concentration, followed by the MacKenzie and then the Dawson. The Isaac has by far the lowest flow-weighted sediment concentration in the catchment, and the sediment concentration at the Yatton does not change as much from drier to wetter years as at other sites in the Fitzroy catchment.

To assess the quality of the estimated sediment load, especially the effect of having TSS concentration data collected from different periods on the long-term load estimates, we re-calculated the mean annual load for the period between 1994 and 2003 when TSS concentration data were collected at all six sites. In addition, we re-developed the rating curves using the TSS concentration data since 1993, and re-calculated the load estimates using the new TSS data set from a common period of monitoring, but with a reduced sample size.

Table 4 Streamflow and estimated sediment loads for various periods ending in 2003 in the Fitzroy catchment.

Rivers	Mean Annual Flow (GL)	Mean Annual Sediment Load (Mt)		
		TSS from 1973	TSS from 1993	
	Flow from 1994	Flow from 1994	Flow from 1974	Flow from 1994
Nogoa	249	0.358	1.23	0.358
Comet	232	0.283	0.598	0.300
Isaac	979	0.128	0.505	0.164
MacKenzie	1,693	0.548	0.740	0.260
Dawson	767	0.219	0.319	0.284
Fitzroy	2,597	1.07	6.99	2.12

Table 4 shows that the period of increased water quality monitoring since 1993 has also been a period of relative low flows. Mean annual flow for 1994-2003 is only about 50% of the 30-year average (1974-2004) for the Fitzroy at the Gap. The decrease of flow of the three major tributaries, namely the Nogoa, Comet, and Isaac, is much greater, ranging from 42% to 62%. This decrease in flow would lead to a dramatic decrease in estimated sediment load for the period from 1994 to 2003. Table 4 shows that the decrease in sediment load would be 65% for the Fitzroy, and vary from 51% to 71% for the three tributaries mentioned above. If TSS concentrations for the common period since 1993 for all sites are used, the amount of decrease in sediment loads as a result of the reduced flow since 1994 is quite similar. If the rating curves for the common sampling period since 1993 were applied to the 30 year period, all sites except McKenzie and Nogoa show a noticeable increase in the estimated sediment load. The increase in the estimated sediment load for the Fitzroy at the Gap is quite dramatic.

4. CONCLUSION

TSS concentrations and flow data for six sites in the Fitzroy catchment were used to develop sediment rating curves to estimate sediment discharge for a common 30 year period from 1974-2003. Sediment rating curves are broadly similar for all the six sites investigated. Variations in the expected sediment discharge among the six sites are considerably smaller than the variations in measured TSS concentrations at a given site. The long-term sediment load of the Fitzroy was estimated at 3.09 Mt yr^{-1} with a 95% confidence about 74%. The estimated load was higher than previous estimates based on extrapolations from other catchments in Queensland. The period since 1994 when water quality monitoring intensified coincided with a period of low flows. Sediment load for the period since 1994 was considerable lower than the long-term average. Most of the sediment came from the Nogoa subcatchment from the west. The sediment load of the Fitzroy at the Gap is consistent with the combined load from its four major tributaries, namely the Nogoa, Comet, Isaac, and Dawson.

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